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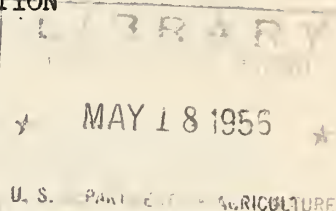
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FACTORS AFFECTING EFFICIENCY OF ELECTRIC FENCE OPERATION *

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For more than twenty years commercially manufactured electric fence equipment has been used in the United States. The idea of substituting one or two wires for a complete fence appeals to both farmers and persons with only academic interest; however, the conditions for providing charged wire which will give an effective shock and yet be entirely harmless have not yet been agreed upon. The engineering problems associated with the use of electric fence systems are:

- (a) Determination of the electrical characteristics of an effective shock as related to the energy limitations required for safety.
- (b) Equipment for producing such an effective shock.
- (c) Conveyance of the effective shock to livestock with minimum energy loss.

Much work has previously been done on the first two problems (1, 2, 3). This discussion will deal with the problems of conveying an effective shock to livestock.

Farmers are using electric fences as a supplement to permanent fences, for temporary fences, and, more recently, for strip grazing. However, such use has not been without operational difficulties. The practice of strip grazing presents special problems in the use of electric fences. This is a progress report of investigations ** undertaken to develop methods and equipment suitable for this practice.

Strip or intensive grazing is the physical limitation of the area of foraging for daily or weekly periods. The principal advantage is better utilization of herbage to an extent that permits a 20% increase in cattle per acre of forage under some growth conditions. The size of the strip grazed varies over the season depending upon maturity of the crop, climatic conditions, agronomic factors, etc. Cattle may be confined to as little as 500 sq. ft. per cow at any one grazing period. Conventional rotated pastures usually have 15,000 to 20,000 sq. ft. per cow.

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One method of strip grazing is shown in Fig. 1. This method requires a minimum of established fences and can usually be used without change of existing boundary fences.

Electric fences used in strip-grazing systems must meet two particular requirements. They must be readily movable, and they must resist unusually severe testing by the livestock. Since the fence is in a new location every day some cows will test it daily. Also, the close proximity of cows and fence results in more frequent contact at night. Because this close confinement of livestock requires more exacting performance of an electric fence, it also provides an excellent means of evaluating fence systems.

In 1954 the Farm Electrification Section of the Agricultural Engineering Research Branch was asked to provide an electric fencing system to control cows in a rotation grazing experiment. For the experiment a 15-acre field was divided into one acre areas as shown in Fig. 2. The entire field was bounded by a woven wire fence.

A single barbed wire was used for the permanent electric fences. Eighteen gauge copper-weld wire was first used on the portable fences. This was later replaced with #13 gauge aluminum. The larger aluminum wire is thought to be more readily visible to cattle. Barbed wire is also usable except that barbs require the use of gloves in moving and they catch in the grass when dragged.

Special portable posts were designed to support the movable fences, and these portable sections attach to the permanent fences by means of gate hooks. In designing the portable posts the following features were chosen as desirable:

- (1) Post resting on the surface of the ground.
- (2) Post stable against upset by livestock or wind.
- (3) Wire attachment by means of integral catch without tools or additional wire clips.

These choices were based upon published reports from the United Kingdom (4) and upon the conviction that the daily moving of posts which must be driven into the ground, with the subsequent attachment of wire, would be too laborious.

Several models were tried during the 1954 season. The most successful post is as shown in Fig. 3. This post is constructed of 3/8-inch steel rod welded so as to form a tripod. The post weighs 3 pounds and several posts stacked together can be carried. At the top of the post a pigtail loop is formed from the 3/8-inch rod. This loop is covered with a length of black polyethylene * pipe.

* Polyethylene is a thermoplastic resin made by the polymerization of ethylene gas under carefully controlled temperature and pressure. Proper compounding with black pigment is required to obtain resistance to weathering. The material is used on farms for cold water lines.

The exact dimensions of this post are not critical. Longer supporting legs with wider spread will give greater stability; however, the post will be more bulky. The height will depend somewhat on the crop and the livestock being controlled.

The use of polyethylene insulators which clamp on the post and which are adjustable in height is even better. Fig. 4 D shows such an insulator as commercially sold in England. This is a simple fence connector that represents an ingenious low-cost design.

The portable posts gave satisfactory results except there were occasional breakthroughs by the cattle. There is some evidence to indicate that control of livestock by electric fence is more effective with barbed wire than with smooth wire, all other factors being equal.

Portable fences on the posts described or on regular ground-driven fences are stretched by hand. This is less taut than desirable but does make for easy movement. However, a tight wire helps resist breakout. The British (4) have a small hand-tightening take-up reel for electric fences. A similar device is sold in hardware stores to tighten the backyard clothesline. These units are somewhat usable but the main difficulty is the winding of the fence wire on a small diameter reel. Wire thus taken up is difficult to stretch when an increase in length is required. A lightweight flexible chain or cable attached to this type tightener would result in a low-cost unit (about \$1 retail).

During the erection and subsequent use of the experimental fences during the season, checks were made with a "megger" (megohmmeter) to locate shorts to ground. From these occasional checks it became apparent that under wet conditions, the resistance to ground of the entire system was less than 100,000 ohms. With the controller being used, 100,000 ohms is the point at which further decrease in fence resistance dims the neon light, indicating fence short. When the resistance decreases to about 3,000 ohms the light is not visible. Actually, in daylight in the field it is difficult to see the indicating light with resistances below 50,000 ohms. Records of breakout of stock were limited; however, there were indications that breakout occurred at night or early morning when wet conditions existed from dew or rain. Checks of resistance to ground of the fence indicated as low as 30,000 ohms. The portable fence post sections using polyethylene insulation maintained very high resistance to ground.

The differences in resistance to ground measured during the 1954 season between the polyethylene insulation and the porcelain insulators, as well as the differences between humid and dry conditions, indicated a need for additional study, so these aspects were more extensively investigated in 1955. Variations due to humid conditions have previously been reported by Dalziel (1), Riley (3), and Nicholas (5). Arrangements were made to purchase a supply of polyethylene insulators direct from England for field tests. The same layout of the field (Fig. 2) was used

in 1955. The permanent cross fences had 17 posts each with a strain insulator at each end, a total of 19 insulators each. The cross fences were connected to the feed line by battery clips to permit easy disconnection for individual section measurements. The portable posts equipped with polyethylene insulators were again used on the movable fences.

Since it was impossible to obtain the polyethylene insulators by the beginning of the 1955 season, tests were begun using porcelain insulators only. All broken or chipped insulators were replaced and the fences were kept free of vegetative growth. Resistance measurements were taken with a "megger" under field conditions with cattle using pastures daily. In terms of a mile of fence (the approximate total of all sections) the resistance of the porcelain system to ground was 5,000 to 50,000 ohms under wet conditions, and 4 to 25 megohms (megohm = 1 million ohms) under dry conditions during the months of April, May, and June.

Early in June the insulators on one-half of the fence test sections were replaced with British polyethylene models. Two types of post insulators and a common type of strain insulator were used. The insulators are shown in Fig. 4, A, B, and C. One type of insulator (A) is very similar in dimensions to conventional porcelain insulators. The other type (B) "butterfly," has considerably greater surface from wire to ground. These insulators are commercially manufactured in England.

Table 1 compares the resistance to ground of porcelain-insulated fence sections and polyethylene-insulated sections. The combined tests represent measurements in the field from April to October 1955 for porcelain and from June to October 1955 for polyethylene. Fig. 5 shows the variation of section resistance with humidity.

TABLE 1

Resistance to Ground - Megohms

	Wet-above 85% humidity			Dry-below 50% humidity		
	Max.	Average	Min.	Max.	Average	Min.
Porcelain (Apr. - Oct.)	-	0.08	0.01	300+*	65.0	-
Polyethylene "A" (June-Oct.)	-	2.4	0.15	300+*	300+*	-
Polyethylene "B" (June-Oct.)	-	8.0	0.5	300+*	300+*	-

* Upper limit of accurate measurement

Weather conditions included approximately 15 inches of rain accompanying two hurricanes during August. No breakout of livestock occurred on the sections of fence during polyethylene insulators. Additional trials will determine if this was due to improved insulation.

The measurement of so wide a range of resistances under outdoor conditions presents many instrumentation problems, so a series of measurements were also made in the laboratory under better controlled conditions.

The electrical insulation quality of insulators which is of concern in electric fence use is the surface insulation resistance. This is a combined function of area and of "surface resistivity." Surface resistivity is the resistance between two opposite edges of a surface film 1 cm. square and is dependent upon a thin film of moisture, sometimes commingled with dust or foreign matter on the surface of the insulating material (6).

To compare the surface resistance of various types, individual insulators were placed on posts outside the laboratory with individual wires attached. These wires extended inside the laboratory so that measurements could be taken more easily without weather difficulties. The leakage resistance of the units is shown in Table 2. These values are for the fence insulators as normally used rather than per cm. of surface area.

Although measurements of resistance of individual insulators were taken from June to November, the tests of November 17 and 19 shown in Table 2 represented the highest and lowest readings of the season. November 19 was wet with a combination of wet snow and rain at approximately 33°F., while November 17 was dry, temperature 45°F., relative humidity 20% with a brisk drying wind.

T A B L E 2

Surface Resistance of Individual Insulators (Megohms)

	<u>Nov. 17 - Dry</u>	<u>Nov. 19 - Wet</u>
Porcelain		
(New in April)	33,700	6-13
	33,700	5-13
Porcelain		
(New Nov. 1)	461,000	4-40
	403,000	75-145
Polyethylene (A)		
(New April)	290,000	4-32
Polyethylene (B)		
(New Aug. 15)	750,000	286
Polyethylene (B)		
(New Nov. 8)	290,000	300-1030

The approximate distance from wire to ground as normally used is porcelain 1.0 inch polyethylene (A) 1.25 inches, polyethylene (B) 1.5 inches.

Discussion

The effective control of livestock is based upon several factors in addition to the controller and its output leads. Lightning arresters, insulators, wire, plants, and moisture in both air and soil are important. The use of better insulators is one means of improving performance of electric fences. The replacement of porcelain with improved insulators such as type (B) polyethylene would result in average resistance to ground 10 times the present values in field use. As projected from data shown in Fig. 5 on a weed-free fence the resistance of a mile of polyethylene-insulated fence (200 insulators) would not fall below 100,000 ohms until the humidity is above 90 percent. Porcelain from the same chart will drop below 100,000 ohms at about 80 percent relative humidity.

Plant growth touching the wire will greatly reduce the effectiveness of electric fences. In the tests reported it was necessary to physically remove grass or weeds touching the fence wire. The control of such vegetation along an electric fence is essential. In pastures it is plants such as orchard grass and timothy that give the trouble. If the area is well matched to the number of cattle the grazing of the cattle will be effective in confinement, as they will inevitably graze the areas under the wire and around the perimeter first. Areas harvested mechanically can be grazed for a day to clean up uncut areas at the edge where the growth is under permanent electric fences. The use of portable posts offers little difficulty from vegetative growth unless the growth reaches a height above which a wire would be too high for cattle. If crops more than 30 inches high are being strip grazed, mowing of a path for the fence is required. Normally the portable fence does not remain in one location long enough for weeds to grow up and touch the fence.

As the insulation resistance of electric fences is increased the characteristics of the system become increasingly similar to those of a capacitor. The possible effects of this circumstance should be investigated more thoroughly. It is conceivable that the use of improved insulators, such as polyethylene, might increase the energy storage of fences through capacitance to a degree which might require a revision of present concepts of desirable characteristics of controller output.

Recommendations

Four types of insulators are required for use in electric fences

- (a) Strain insulators for the ends of the fence.
- (b) Line insulators for permanent fences.
- (c) Line insulators for portable fences.
- (d) Gate insulators used in access gates.

All types should have the following characteristics.

- (a) Material of high surface resistivity under conditions of 90 percent humidity, equal to or better than polyethylene.
- (b) Volume resistivity equal to porcelain under conditions of 90 percent humidity.

- (c) Physical shape which provides maximum path of surface leakage and provides good self-cleansing action by rain with no recess areas to harbor insects.
- (d) Resistant to breakage
- (e) Stable characteristics throughout useful life

For insulation purposes the electric fence external to the controller must be considered similar to other electric lines carrying more than 600 volts. This is to prevent leakage currents, and not because of safety hazards. This includes lead wires, lightning arresters and cables under roads. Ordinary rubber-covered wire as used in farm wiring is not suitable for leads unless used with insulators of the improved type recommended for bare wires. Rubber milking machine hose is extremely poor as insulation.

Summary

For engineering problems associated with the use of electric fences are: (a) determination of the electrical characteristics of an effective shock as related to the energy limitations required for safety; (b) equipment for producing such an effective shock; and (c) conveyance of the effective shock to livestock, with minimum energy loss. This paper concerns the latter problem. The control of livestock in strip grazing requires a more exacting performance of the electric fence and thus provides an excellent means of evaluating electric fence systems. A portable post with quick wire attachment has been developed to simplify moving of the fence. Use of polyethylene insulation in portable fences resulted in improved performance as compared to conventional porcelain.

Additional tests of polyethylene insulators indicated ten times greater surface resistance than conventional porcelain insulators under comparable conditions. Measurements indicate a need for improved fence insulators which will maintain high surface resistance under all weather conditions and be resistant to breakage. Four types of insulators are needed: for strain points, for gates, for permanent fences, and for portable fences. Additional information is needed concerning the durability of polyethylene and other materials of high surface resistance which might be used in commercial production.

In addition there is a need to determine the effect of improved fence insulators on the electrical output requirements of fence controllers to obtain safe yet effective shock; also the possible importance of capacitance effects as leakage is decreased should be investigated.

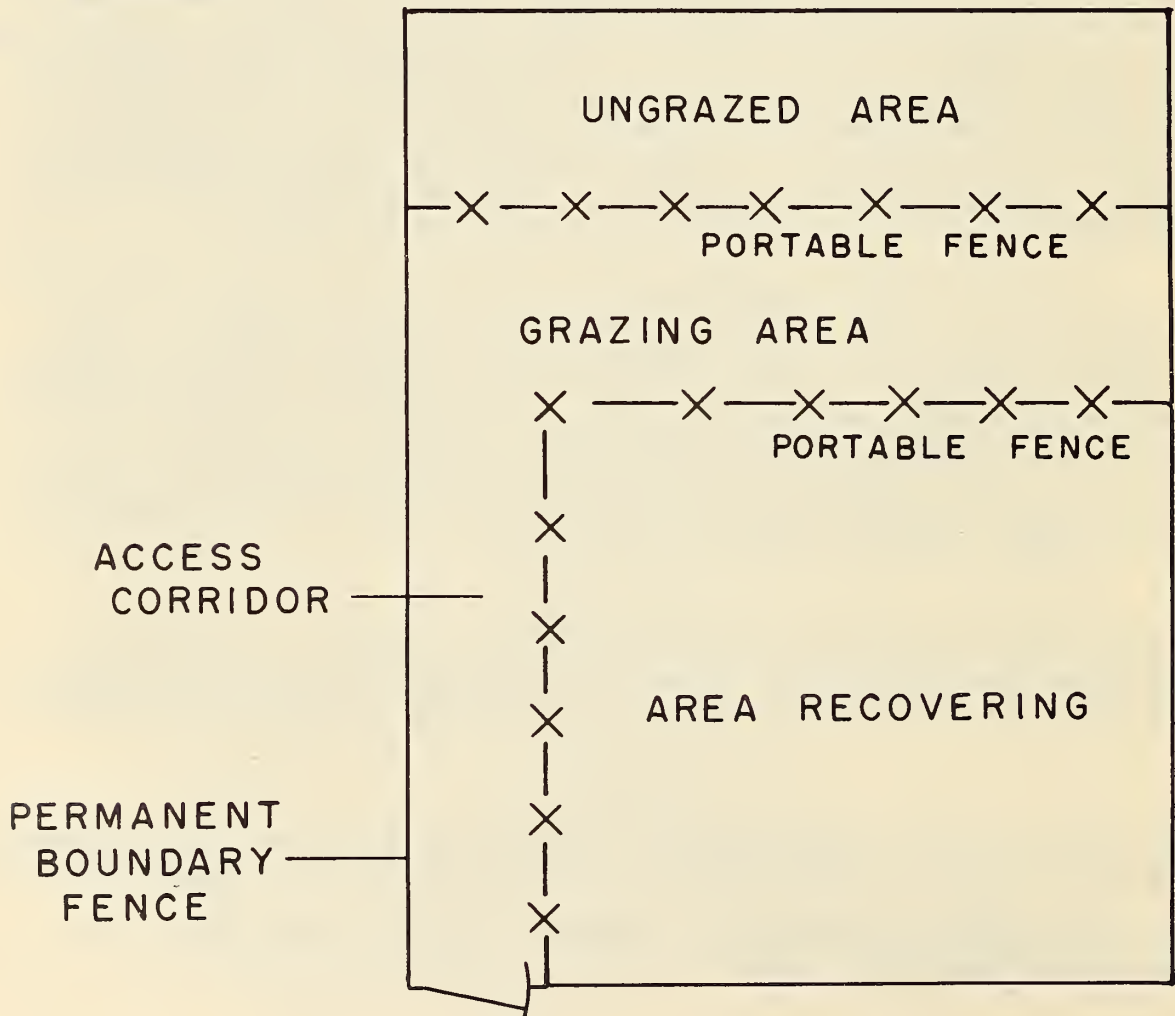
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TYPICAL STRIP-GRAZING SYSTEM

FIGURE 1



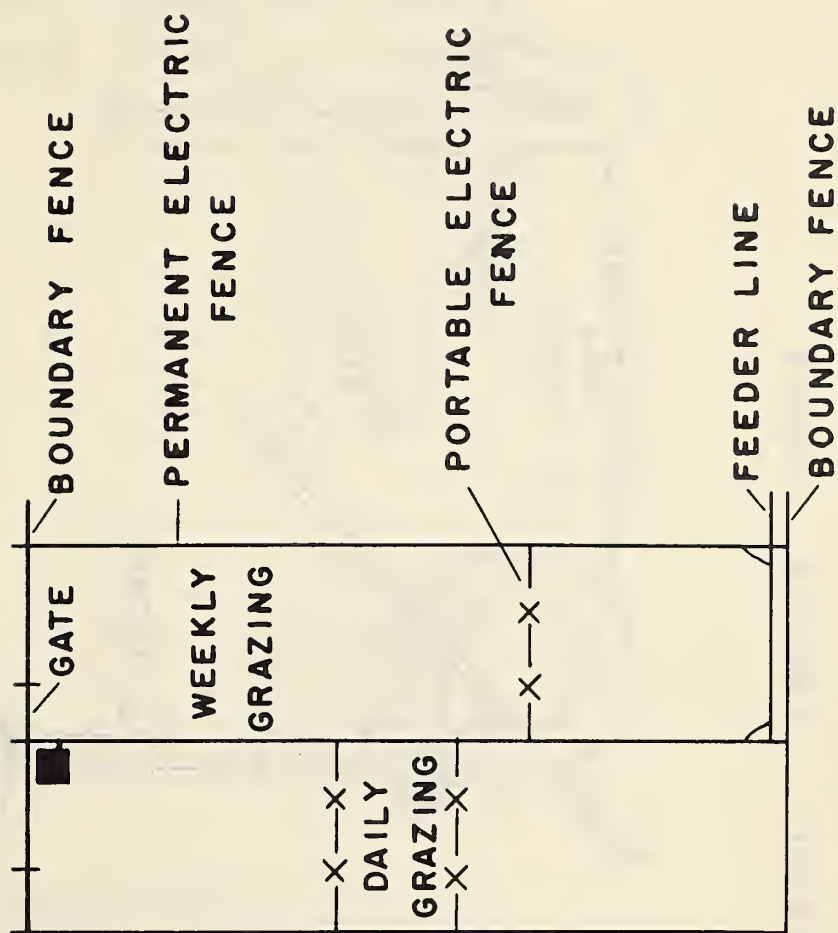
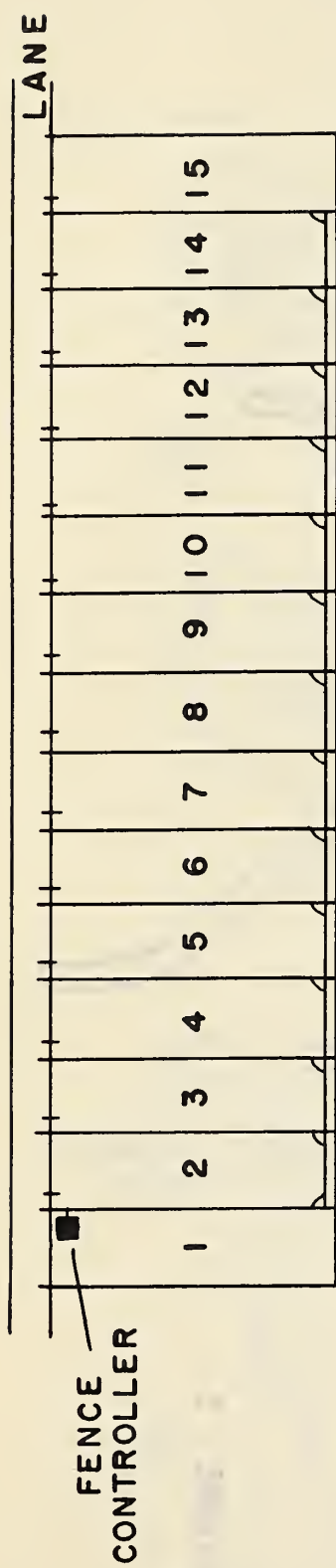


FIGURE 2

STRIP GRAZING
EXPERIMENTS

Beltsville, Maryland

PORTABLE ELECTRIC FENCE POST

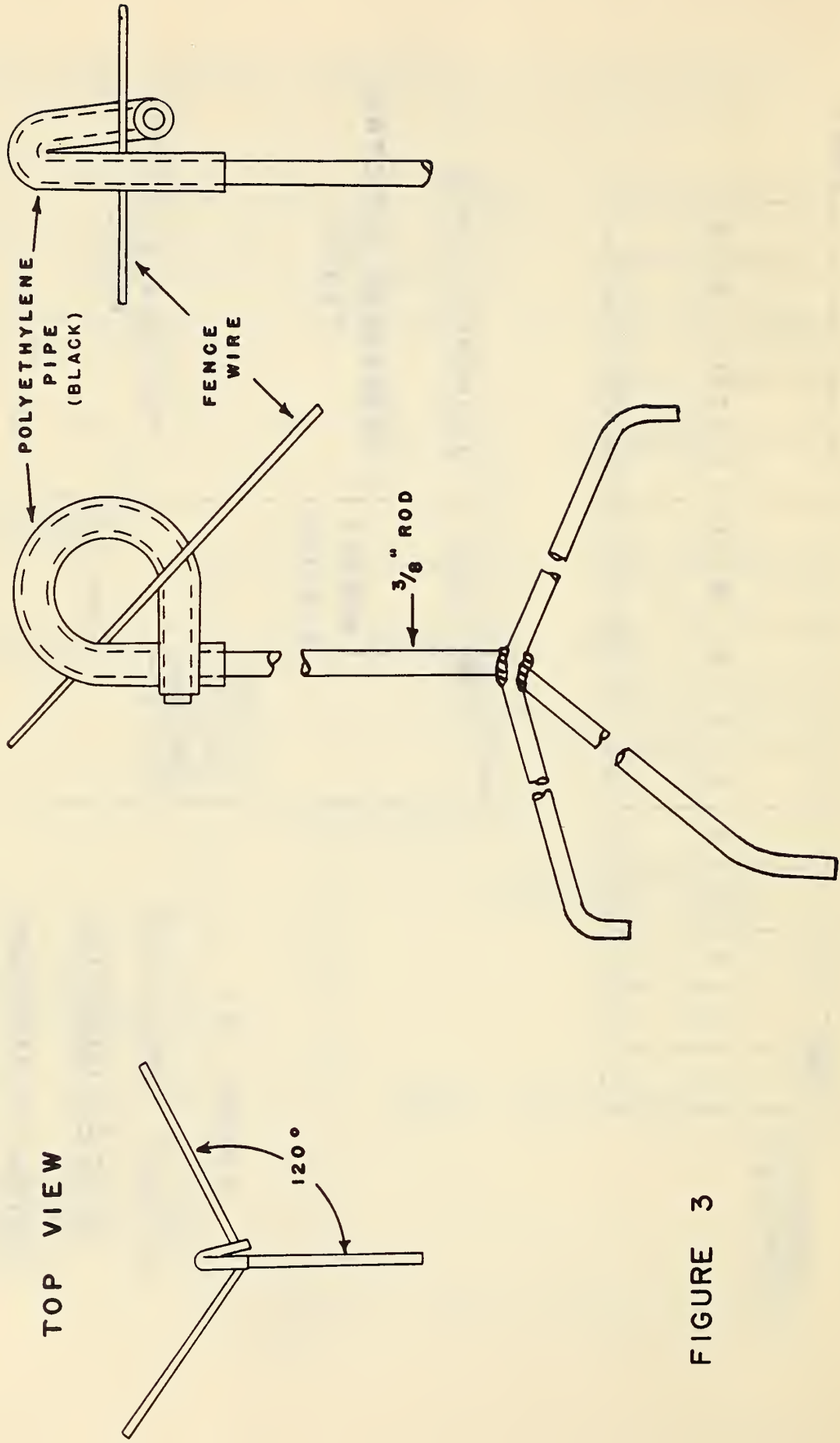
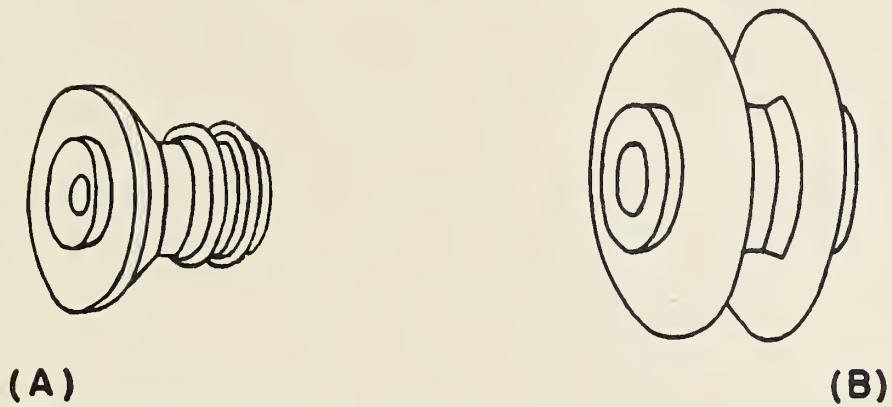


FIGURE 3

FIGURE 4
BLACK POLYETHYLENE
FENCE INSULATORS



LINE-POST INSULATORS

